largest portion of all the commercial catch. The rivers of the Northwest flowing into the Pacific Ocean, particularly the Columbia, are natural spawning grounds for salmon. Their migration upstream from the sea supports one of the important industries of the region. The average yearly volume and value of the canned salmon pack from the Columbia is about 360,000 cases worth nearly four and a half million dollars. During recent war years, the pack has nearly doubled.

42. The recreational value of mountains, forests, lakes, and streams has become recognized as another important natural resource. It has been estimated that over $200,000,000 is expended annually on recreational travel in the Pacific Northwest. Most of the recreation areas are publicly owned and maintained.

43. *Industries.*—Past industrial activity has centered primarily upon lumbering, fishing, mining, farming, and transportation. As the region has developed, construction, processing, and manufacturing activities have become increasingly important. A considerable part of the agricultural production is processed in the region, giving rise to industries such as fruit and vegetable packing, meat packing, and flour milling. In the forest-products industries, although manufacture of lumber and timber products is still by far the leading industry, the production of pulp, paper, and furniture are becoming increasingly important. Manufacture of forest products and processing of foods normally constitute the major part of the manufacturing activity of the region. The most significant recent industrial development is the establishment of light-metal and special-alloy plants for war production. Electrolytic pig-aluminum plants, aluminum rolling mills, metallic magnesium, and ferro-alloy plants are located throughout the Northwest. They are heavy consumers of electric power, and were located here because of the power supply and existing transmission network. Many other war plants such as shipyards that now consume large blocks of power may become dormant after the war, but some of the light-metal and alloy plants may remain active factors in the industrial and power-market situation.

44. *Existing power development.*—Reports of the Federal Power Commission show that installed electric generating plant capacity in the five-State region at the end of the year 1940 was approximately 2,300,000 kilowatts. Of this total, about 1,800,000 kilowatts were available in hydroelectric plants and the remainder in fuel-consuming plants, principally steam. By the end of the year 1944 the total rated capacity of generating plants had increased to 3,535,843 kilowatts, which increase has been largely used to supply the increased demand for electric energy brought about by the war. Until about 10 years ago, hydroelectric power was developed principally by private enterprises and by a few municipalities such as Seattle and Tacoma. Recent expansion of generating facilities in this region has been largely in connection with Federal multipurpose projects.

45. Three principal power plants of the region are located on the main stem of Columbia River—at Grand Coulee Dam, mile 597 above the mouth; at Rock Island Dam, mile 453; and at Bonneville Dam, mile 143. The Grand Coulee plant, completed in 1942 (except for additional generating units) by the United States Bureau of Reclamation, has an installed rated capacity of 818,000 kilowatts (including 20,000 kilowatts in house units), and will have an ultimate installa-

will depend largely on the status of industries and the extension of irrigation.

38. *Resources.*—The principal resources of the region include forests, agricultural lands, minerals, fish, recreational facilities, and water power. The forests of the Pacific Northwest—Oregon, Washington, Idaho, and western Montana—cover approximately 100,000,000 acres, or about 15 percent of the wooded area of the United States. The standing timber is estimated at 883,000,000,000 board feet, and consists largely of Douglas fir and various types of pine. About half the total timber is in Federal ownership. Saw-timber production in the region was about 10,000,000,000 board feet in 1940. Paper and pulp, plywood, shingles, poles, piling, and fuel are important timber products also.

39. Agriculture has been of major economic importance since the early days of settlement. The Sixteenth (1940) Census showed that over 97,000,000 acres are in farms, distributed by States as indicated in the following tabulation:

State	Land in farms (acres, 1940)		
	Total	Cropland	Irrigated
Washington	15,182,000	3,631,000	615,000
Oregon	17,988,000	2,937,000	1,048,000
Idaho	10,298,000	2,997,000	2,274,000
Montana	46,452,000	6,245,000	1,696,000
Utah	7,302,000	1,043,000	1,176,000
Total	97,222,000	16,853,000	6,809,000

The total value of crops and livestock produced in 1939 was about $465,000,000. Use of the land differs greatly with variations in soils, climate, topography, and economic conditions. Large areas east of the Cascades are utilized mainly for grazing and, with adjacent hay lands, support large numbers of range livestock. Some areas are suitable for drought-resisting crops such as wheat, whereas in others, dairy farming and specialty crops, such as fruits, berries, and vegetables, have been developed through irrigation. West of the Cascades mixed farming is general throughout the lowlands where fertile soils and adequate rainfall exist

40. Mining was a controlling factor in the early settlement of the region. Such famous districts as Butte, Coeur d'Alene, and Metaline have produced and still yield great riches. The value of minerals produced in 1940 exceeded $264,000,000. Gold, silver, copper, lead, zinc, and mercury are the principal metals produced. The region has substantial deposits of nonmetallic minerals, but their production, with a few exceptions, has been of minor importance. The principal nonmetals found are coal, petroleum, limestone, sand, gravel, and clay. In addition to those mentioned, known deposits of other metallic and nonmetallic minerals exist, but because of their inaccessibility or comparatively low grade they have heretofore remained untouched and unevaluated.

41. Fish are a primary resource of the region. A wide variety is found in the coastal waters of the Pacific Northwest, including salmon, steelhead, halibut, pilchard, albacore tuna, cod, and various shellfish. Salmon are the most important, and normally constitute the

tion of 1,974,000 kilowatts (including 30,000 kilowatts in house units). The Rock Island plant, completed in 1933 by the Puget Sound Power & Light Co., has a rated capacity of 60,000 kilowatts (or 80,000 kilowatts by adding flashboards) and a planned capacity of 240,000 kilowatts. The Bonneville plant, completed by the Corps of Engineers, United States Army, in 1943, has an installed capacity of 518,400 kilowatts. Columbia River plants are now connected with each other and with practically the entire generating capacity of the five-State region through the transmission system of the Bonneville Power Administration and the various utility company lines. The multi-purpose project for the main Columbia River at Umatilla, Oreg., authorized by the River and Harbor Act of March 2, 1945, probably will have an ultimate installation of 966,000 kilowatts, with room for further expansion if required. The power installation proposed initially at the dams authorized by the same act for Snake River is 512,000 kilowatts and ultimately, 1,071,000 kilowatts.

46. *Irrigation.*—As rainfall over large areas east of the Cascades is insufficient for crops other than small grains and grass, irrigation has been developed extensively under private and Federal enterprises. The following table, based on the 1940 census and latest published data of the United States Bureau of Reclamation, indicates the extent of existing irrigation development in the five-State region, and the extent of ultimate development on completion of proposed construction programs:

Item	Irrigation as of 1940		Irrigation on completion of proposed construction programs	
	Acreage	Investment Dec. 31, 1939	Acreage	Ultimate investment
Total private	4,349,217	$159,944,000	5,160,511	$163,948,000
Total Federal	2,460,224	158,342,000	5,149,360	718,662,000
Grand total	6,809,441	318,286,000	10,309,871	882,610,000

47. *Transportation.*—Despite the mountain barriers, the productive areas of the region are well served by modern systems of transportation. Several transcontinental railroads passing through the region to the Pacific coast and coastal routes extending from Canada to California, together with a network of branch lines, connect population and production centers of the region with tidewater terminals on the coast and with markets in the interior. Similarly, Federal and State highways, and a network of secondary and county roads, provide access to all improved areas, and much of the region's commerce now flows over this highway system. Established east-and-west transcontinental and north-and-south international air lines cross the region. Branch-line operation, however, has been conducted only on a limited scale.

48. *Navigation.*—In pioneer days the Columbia formed the main artery for transportation of commodities and people, but with the advent of the railroads, and later the highways, river commerce above Snake River rapidly dwindled to insignificant proportions and in some sections finally disappeared. Present commercial navigation in the region is confined to large lakes of the upper tributaries, the Columbia

River Reservoir, isolated river sections, and the lower reaches of Columbia River and tributaries below Priest Rapids, Wash. The lower Columbia is navigable by deep-draft vessels to The Dalles, Oreg., and by river-type craft to Priest Rapids.

49. *Bridges.*—There are five bridges over Columbia River in the reach between Rock Island and Grand Coulee Dams. Pertinent data on the five bridges are given in the following tabulation:

Miles above mouth	Owner and purpose	Type and number of spans	Channel spans: Clear width normal to channel	Channel spans: Clear height above: Mean low water	Channel spans: Clear height above: High water	Date of completion	Plans approved by War Department
456.85	Great Northern Ry.; railroad bridge.	Fixed, 2	Left, 225; right 400	96	47	1926	June 28, 1924
465.05	State of Washington; highway bridge.	Fixed, 4	Center, 500	104	45	1908	Apr. 13, 1906
504.05	Wenatchee-Beebe Orchard Co.; highway bridge.	Fixed, 1	626	86	45	1919	Apr. 10, 1919
530.05	State of Washington; highway bridge.	Fixed, 5	Left, 330.75; right, 330.75.	92	47	1928 1939 [1]	Aug. 17, 1927 June 21, 1939
596	U. S. Department of the Interior; highway bridge.	Fixed, 3	Left, 200; center, 550; right, 200.	[2] 100	30	1936	Feb. 26, 1934 Apr. 10, 1934

[1] Partial reconstruction.
[2] Vertical clearance specified applies to central 437 feet of center span only Refers to low water (933± feet above mean sea level).

50. *Reservations.*—Approximately 68,000,000 acres of the five-State region are in national-forest reservations; 13,600,000 acres are under the jurisdiction of the Office of Indian Affairs, and more than 2,500,000 acres are in national parks and monuments, administered by the National Park Service. The region also has a considerable acreage of State-owned lands.

51. Reservations as to the use of Columbia River waters were included in treaties between the United States and Canada dated August 5, 1846, and January 11, 1909. The first of these treaties defined the international boundary westward to the Pacific and provided that navigation on Columbia River below the boundary should remain open to certain commercial interests. The second treaty provided for settlement by the International Joint Commission, of all questions that might arise in connection with any change affecting the natural level, flow, or navigability of boundary waters. In connection with Grand Coulee Dam, the Government of the United States, under the provisions of the treaty of 1909, filed application with the International Joint Commission for approval of the dam and the proposed method of operation of the reservoir. Order of approval was issued by the Commission, December 15, 1941, on conditions involving provision for the protection and indemnification of all interests in British Columbia by reason of damage resulting from the construction and operation of Grand Coulee Dam and reservoir, together with certain special provisions relating to jurisdiction, backwater effects, fish propagation, stream records, and curtailment of power production. Inasmuch as Canadian interests will be insulated

by Grand Coulee Dam from any effects that might be imposed upon stream flow by Foster Creek Dam, no conflict with the provisions of the 1909 treaty, nor with policies of the International Joint Commission, is anticipated.

52. *Description, vicinity of Foster Creek.*—As shown on plate 3, the proposed dam and reservoir lies in the southern part of Okanogan County and the northern part of Douglas County. It is located in a stretch of the Columbia that flows through a gorgelike depression, from 300 feet to 2,000 feet below the surface of, and bordering, the northern edge of the Columbia Plateau. The dam site is 545 miles by river above the mouth of the Columbia, 200 miles downstream from the international boundary, and 51 miles downstream from Grand Coulee Dam. The principal communities and agricultural lands of the surrounding area are in the valleys of the Okanogan and Methow Rivers, which join the Columbia 12 miles and 22 miles, respectively, downstream from the dam site. Irrigation is practiced in both valleys. The surrounding uplands are forested and are largely embraced in Chelan National Forest.

53. The population is sparse and communities are widely scattered. Okanogan County, with an area of 5,295 square miles, had a population of 24,546 in 1940, and Douglas County, with an area of 1,841 square miles, had 8,651 in 1940. The largest city within the two counties is Omak, 35 miles from the dam site, in Okanogan County, with a population of 2,918. Brewster, also in the same county, with a population of 447, is located 14 miles downstream, and Bridgeport, Douglas County, population 320, is 1½ miles downstream. The nearest larger city is Wenatchee, 80 miles downstream, in Chelan County, with a population of 11,620 in 1940. The economic activity of the area is centered about farming, lumbering, and mining. The value of all farm products sold, traded, or used by farm households in the two counties in 1939 was in excess of $8,000,000. Fruit, wheat, and livestock are the principal agricultural products. About two-thirds, or 2,235,000 acres of Okanogan County consists of forest land, the principal product of which is box shooks derived from Ponderosa pine, the predominant forest type. Mining of metallic minerals is also a minor activity in Okanogan County, the 1939 output of gold, silver, copper, and lead amounting to $318,142. Adjacent Chelan County, however, accounted for nearly $4,000,000 in copper in 1939 from the Holden mine near the head of Lake Chelan.

54. The railroad nearest to the dam site is the Great Northern Railway at Brewster, about 14 miles downstream. A branch of the same railroad system serves Mansfield, 18 miles to the south. Bridgeport is linked to Brewster by a bituminous-surfaced State highway that crosses Columbia River over a steel truss bridge at Brewster. There is no bridge crossing the Columbia between the latter and the bridge at Coulee Dam. The latter will not be affected by the proposed project. A surfaced road leads from Bridgeport to a point 3 miles past the dam site and a rough dirt road continues on to Coulee Dam. A hard-surfaced road leads up Foster Creek to Mansfield. No improved road is near the dam site on the north side of the river. The Northwest Airlines transcontinental airway passes about 30 miles south of the project, with service to Wenatchee, 79 miles southwesterly, and Spokane, 143 miles southeasterly, by highway.

55. In the section of the Columbia extending from Priest Rapids to Grand Coulee Dam, within which Foster Creek Dam site is located,

the only navigation of commercial importance was the regular service maintained from 1888 to 1912 on the 68-mile reach from Wenatchee to the mouth of Okanogan River, and the intermittent traffic between Pateros and Bridgeport prior to 1928. No record exists of any commercial navigation on the reach from Foster Creek to Grand Coulee Dam. As a result of channel improvements (see par. 58) made by the Engineer Department, under authorization of various congressional acts prior to 1917, the controlling depth from Wenatchee to Coulee Dam has been 4 feet.

56. Along Okanogan River some 40 miles north from the proposed Foster Creek Dam site, the Okanogan irrigation project has been developed by the United States Bureau of Reclamation. The total acreage of land irrigated in 1940 was 3,174, and the ultimate irrigable acreage in this enterprise is estimated at 5,356. The Colville Indian Reservation, on which about 1,200 Indians reside, borders the right bank of Columbia River throughout the Foster Creek Reservoir and Dam site.

57. Grand Coulee Dam lies only 51 miles upstream by river and 30 miles cross country from Foster Creek. Its proximity and location impose several important, and in some cases controlling, conditions upon both the functions and the design of the project. The height of dam will be limited by the elevations of Grand Coulee Dam tail water. Regulation of the 5,200,000 acre-feet usable stored water in Columbia River Reservoir will have a direct bearing on prime power, and hence on the size of installation, at Foster Creek. The main switching yard at Grand Coulee Dam and the connecting transmission network define both the logical source of power for construction purposes and the logical point of interconnection of the two projects. Effects of the proposed dam construction upon through navigation and fish migration are nil. Grand Coulee Dam completely obstructs both. There is no navigation in the stretch of river between Foster Creek and Grand Coulee Dam. Migratory fish have been transplanted to lower tributary streams. No recreational interests now center on the reach of the Columbia that will be modified by the proposed project. On the contrary, like Grand Coulee Dam, this project will add an attraction to the region for residents and visitors.

58. *Existing projects.*—Existing navigation projects are confined mainly to the lower Columbia and tributaries. There are 24 active projects, involving raising of toll bridges and construction of channels, canals, locks, breakwaters, and Bonneville Dam. The total cost to June 30, 1943, was approximately $110,000,000, including some $700,000 contributed by local interests. Navigation projects on the main stem of the upper Columbia were adopted by the River and Harbor Acts of March 2, 1907, and June 25, 1910, providing for open channel work between Wenatchee and Bridgeport, and rock removal to obtain a depth of 7 feet between Bridgeport and Kettle Falls. The work was completed in 1917 at a total Federal expenditure of $282,083.11 and a local contribution of $50,000. Existing flood-control projects also have been confined mainly to the lower Columbia and tributaries. A total of nearly $31,000,000 was expended in the period from 1939 to 1944, inclusive, for construction of levees, dikes, revetments, enrockments, reservoirs, and for other general flood-control work. The River and Harbor Act of March 2, 1945, authorizes construction of the multiple-purpose Umatilla (McNary) Dam on the main stem and a series of dams on lower Snake River.

59. *Improvements by other Federal and by non-Federal agencies.*—Improvements along the main stem of Columbia River made by other Federal agencies usually have been for irrigation and power. The most important of these is the Columbia Basin project being developed by the United States Bureau of Reclamation. The project, in addition to the multiple-purpose Grand Coulee Dam, contemplates a system of distribution reservoirs, pumping plants, and canals for the irrigation of about 1,200,000 acres of land in central Washington. The project has been under development since 1934. The dam and left bank power plant have been substantially completed. Construction costs to June 30, 1944, were $186,000,000. The total cost of the project is estimated by the Bureau of Reclamation to be $487,000,000.

60. The principal non-Federal development on the main stem is the Rock Island project, previously mentioned. It was completed in 1933 by the Puget Sound Power & Light Co. under Federal Power Commission License No. 943, dated January 31, 1930. A small power project was developed at Priest Rapids by the Priest Rapids irrigation district, but has been acquired by the Government for military purposes. Other non-Federal improvements have been confined generally to the lower Columbia and have consisted mainly of improvements in the interest of maritime commerce, and minor flood-control and drainage work by various districts organized under State law or by private organizations and individuals.

61. *Improvements desired.*—At a public hearing held in Brewster, Wash., on July 2, 1945, approximately 400 representatives of local, State, and national interests urged the immediate authorization of Foster Creek project for early postwar construction. No opposition to the project was voiced. Lumbermen and miners cited the expansion of pulp and mineral production that will follow further low-cost power development. Agriculturists spoke at length of the fertile lands that can be irrigated in the vicinity. The fishing industry, represented by packers, workers, State, and Federal officials, pointed out that this project will not adversely affect the salmon industry, but will permit development of the Columbia for agricultural and industrial purposes to proceed while allowing the fishing interests further time to study the problem and take such steps as may mitigate the consequences of further downstream construction. Individuals and agencies familiar with the development of the Columbia referred to the great assistance rendered the war effort by the light metals industries that were located in the region because of abundant, cheap power, and expressed the opinion that the power output of Foster Creek project will be needed by the time it can be made available. Self-liquidating advantages were stressed as providing sound development of a national asset without requiring a treasury subsidy or local contribution of funds. A report of the hearing constitutes appendix XI.[1]

CHAPTER III—PROJECT PLAN

62. A table of pertinent data summarizing the salient physical statistics of the proposed project has been placed at the beginning of this report for ready reference. Maps and cross sections appear at the end of the report.[2] The table and illustrations show many details

[1] Not printed.
[2] Only plates 1, 2, and 3 are printed.

and relationships more readily than they can be described in words. Therefore, the descriptions herein are rather brief, and outline only the main features and the principal reasons for their adoption. More complete technical discussions are presented in appendixes [1] to the report.

63. *Functions of the project.*—Production of electric power is the primary function of the proposed project. The estimated cost per kilowatt of prime power is low. The potential prime power (available 100 percent of time) under two conditions of stream regulation is given below. The figures are based on observed stream flow depleted by estimated future irrigation, with average pool elevation 937.5 and assumed efficiencies.

Power study No.	Conditions	Prime power megawatts
3b	Foster Creek using regulated flow from present upstream reservoirs: Columbia River Reservoir, Flathead and Kootenay Lakes each operated to obtain maximum prime power at its own site	479
6	Foster Creek when coordinated with Grand Coulee project. Flathead and Kootenay Lakes operated to obtain maximum prime power at their own sites	526

The initial generating installation proposed herein is 960,000 kilowatts, with 15 Francis turbines rated at 162-foot net head. Space will be available for 1 additional unit at the initial powerhouse. Regulation by future upstream storage reservoirs would substantially increase the prime power. Therefore, an installation of greater size ultimately may be required. Expansion of the proposed installation has been considered and found to be entirely practicable to whatever extent may be required by probable future storage and load developments. The project is close to the existing regional power-distribution system, and its transmission line distance to the Puget Sound industrial area is less than that of Grand Coulee Dam. Topographic features and foundations are favorable to both the construction and operation of the project. The land required is mostly too rough and arid for cultivation. Highway relocations will involve relatively small expense. Rights-of-way for railway and highway approaches from Brewster will traverse land of low value.

64. Navigation of Columbia River is blocked at Grand Coulee Dam, 51 miles above Foster Creek site. The intervening reach is a succession of rapids with only an occasional smooth stretch. There are no towns between Bridgeport and Coulee Dam and the adjacent territory is sparsely settled. Although a few steamers traveled beyond Foster Creek 30 to 60 years ago, there never was any regularly scheduled service. Even sporadic river traffic has ceased since the coming of railroads and automobiles. Foster Creek Dam would bar through navigation but would provide slack-water navigation upstream to Grand Coulee.

65. Irrigation service to about 15,000 acres may be accomplished by canals from Foster Creek pool, according to information furnished by the Bureau of Reclamation. About 13,000 acres of the land lies in the lower reaches of Okanogan Valley. About 3,000 acres would be served by gravity, whereas pumping would be required for the

[1] Not printed.

other 10,000 acres in Okanogan Valley. A branch canal and siphon crossing Okanogan River would reach Brewster Flats with a lift of 300 to 400 feet. The remainder of the area lies on Bridgeport Bar on the left bank of the Columbia. Possibly 2,000 acres could be irrigated by gravity, although the gravelly nature of some of the lands and the absence of a careful land classification make this estimate highly tentative. Data sufficient to determine the merits of the general plan suggested are not available, but the irrigation facilities, if and when desired, can be incorporated in the Foster Creek project without material modification of the latter. The same lands contemplated in the Bureau of Reclamation's suggestion can be irrigated by direct pumping from Okanogan River or from the Columbia below Foster Creek without the construction of a canal from Foster Creek pool. Selection of the better plan will depend upon the relative costs.

66. Flood control is not an objective of the project. A very large reservoir would be required to effect beneficial reduction in the crest discharge of Columbia River owing to its long, flat peak. The reservoir proposed will be too small to have any noticeable effect during damaging floods. Aside from flood control, however, regulation at Foster Creek of fluctuating flows released at Grand Coulee Dam will have many advantages, particularly for navigation and irrigation. When more units are installed at Grand Coulee and load characteristics resume a normal aspect, it is anticipated that this plant will experience large daily load variations with corresponding fluctuations in the water released. During the period prior to completion of the proposed installation at Foster Creek, the latter can be operated primarily as a base-load plant, permitting Grand Coulee to follow load demands without concern for the effects on river flow. Daily fluctuations below Grand Coulee can be smoothed out at Foster Creek during this period, thus avoiding serious detriments to irrigation and navigation interests that attend large and frequent changes of river stage.

67. *Datum.*—Elevations are based on United States Coast and Geodetic Survey bench mark M–56 at the dam site, the preliminary unadjusted elevation of which is 838.612. On this datum, and as determined by a checked, third-order line of levels, United States Geological Survey bench mark Osborne No. 2 at Grand Coulee Dam has an elevation of 1,122.75, whereas the United States Geological Survey elevation used by the Bureau of Reclamation in its work at Grand Coulee Dam, is 1,123.75. Therefore, a difference of 1.00 foot exists between the datum of this report and the datum for the Grand Coulee project.

68. *Investigations.*—Surveying undertaken for this report includes topography of the dam and reservoir areas referred to United States Coast and Geodetic Survey horizontal and vertical controls; river soundings, water surface profiles, and gagings from Grand Coulee Dam to Bridgeport. Water surface profiles at various stages are shown on plate 5.[1] Geologic examinations and subsurface explorations by seismograph, churn drill, diamond drill, trenches, tunnels, and test pits were made at proposed dam axes and their environs, involving about 1 mile of river channel and contiguous banks. Drill logs are shown on plates 8 and 9.[1] Part of the exploratory work was directed toward locating and testing aggregates for concrete and toward determining permeability of the right abutment materials. The general

[1] Not printed.

nature and extent of field investigations are shown on the following maps:

(a) *Columbia River, Wash., Foster Creek project—Topography and profiles, Grand Coulee Dam to Foster Creek.*—15 sheets, 27 by 40 inches. Horizontal scale 1 inch equals 400 feet, contour interval 25 feet. Appendix X,[1] plates A–1 to A–15, inclusive (reduced).

(b) *Columbia River, Wash., Foster Creek project, site map.*—1 sheet, 27 by 40 inches. Horizontal scale 1 inch equals 1,000 feet. Contour interval 20 feet. Plate 4[1] (reduced).

(c) *Columbia River, Wash., Foster Creek project—Foundation exploration, general plan.*—1 sheet, 27 by 40 inches. Horizontal scale 1 inch equals 200 feet, contour interval 10 feet (original, 2 feet). Plate 7[1] (reduced).

69. Laboratory tests and analytical studies were made of the samples obtained in the subsurface explorations. A series of model studies by the methods of electrical analogy, and mathematical computations of seepage characteristics of the right-abutment materials, also were conducted in the laboratory. Office investigations of special importance dealt with the reservoir backwater, power capabilities, hydraulic and structural design factors, costs, and economic phases of the proposed development. Structural features are shown on plates 11, 12, and 13[1]; power characteristics on plates 14 and 15.[1] Prospective damages and the cost of all relocations were estimated. Investigations by cooperating agencies consisted of stream slope and discharge measurements in the vicinity of Foster Creek conducted by the United States Geological Survey, and consideration of the effects of the proposed project upon fish life by the United States Fish and Wildlife Service.

70. *Other sites considered.*—Several alternate dam axes were investigated at locations shown on plate 7.[1] The general dimensions and arrangements of the best plans at the various axes are quite similar, but substantial differences in the engineering problems, estimated costs, present power capabilities, and potentialities for ultimate expansion decisively favor the location farthest downstream. The axis designated No. 1 is the site discussed in the report under review. It lies farthest upstream of those studied. Doubtless it received preferred attention originally because of the outcropping ledges of granite in the river bed, the ample space available for spillway and intake, and its location near the foot of Foster Creek Rapids. Enormous basalt erratics on the right bank have almost vertical faces from 50 to 100 feet high and steep slopes above and below. Between the basalt masses and the bedrock, current explorations have revealed great volumes of highly pervious sand and gravel. The basalt, or a major portion of it, would have to be removed to permit sealing off this underlying pervious material. Such a process would impose considerable difficulty and expense upon construction at this axis. The outcropping ledges of granite in the river bed are badly jointed and considerably weathered, thus requiring extensive stripping to expose fresh, sound rock. More grouting would be required here than at the downstream locations mentioned hereafter. Ledges along the left bank extend to the middle of the river, deflecting the main current into a channel along the right bank that is apparently eroded rather deeply, and in which it has not been possible to get soundings because of the turbulence and high velocity of the current. At ordinary low-water stages the velocity is 7 to 10 miles per hour (10 to 15 feet per second).

[1] Not printed.

There is less turbulence at higher stages, but the velocity is greater. Such conditions would make diversion of the river at this axis expensive because of the long cofferdams required and the difficulty of placing and maintaining them. Furthermore, the drop in water-surface elevation makes available nearly 3 feet of additional head between axis No. 1 and the site selected. The prime power added by the increase in head would be worth at least $2,000,000 based on the investment cost of the project per foot of available head. These considerations prompted the investigation of several axes lying downstream from the one discussed in the report under review.

71. Axis No. 2 is one-half mile downstream from No. 1. The velocity at axis No. 2 is appreciably less, it is more uniformly distributed over the cross section, and the stream is noticeably smoother. River diversion would be less hazardous and less expensive here than at axis No. 1. The left bank consists of good quality granite protruding occasionally through a thin mantle of sand and gravel, and having a contour favorable to the arrangement of the intake canal. More excavation would be required for penstocks and powerhouse than at axis No. 1, but very little would be needed for the tailrace. There is little overburden in the stream bed. The right bank is on a fairly uniform slope averaging 1 on 1½. The exposed basalt haystack rocks have volumes measured in tens of cubic yards, whereas at axis No. 1 the basalt forms cliffs containing thousands of cubic yards. Hence the sealing of the underlying pervious material at axis No. 2 would require only a fraction of the trimming and excavation needed at the upstream location. An additional 1.3 feet of head would be worth about $850,000 in favor of axis No. 2, valued on the basis of project cost per foot of available head.

72. *Best site.*—Axis No. 3–C is 2,200 feet downstream from axis No. 2, and one-fourth mile upstream from Foster Creek. The river channel is straight for a mile below, assuring favorable spillway discharge conditions during extreme floods. The channel is wider and the depth more uniform than at either upstream site, hence velocity and turbulence are materially less. Cofferdams can be shorter, yet provide more interior working space because of the wider channel. There will be less hazard involved in placing them and a greater flood can be passed without overtopping.

73. It was formerly believed that the bedrock underlying the right bank had a definite downward slope in a downstream direction. That supposition is not supported by the further drilling and seismic observations made for this report. The elevation of bedrock from axis No. 1 to axis No. 3–C varies through a range of about 15 feet, but the variations appear to be merely local and do not indicate any definite advantage at upstream sites.

74. Drill hole No. 52 in midchannel about 400 feet downstream from axis No. 2 shows a pocket of soft, badly weathered granite 13 feet deep which would have to be removed if the dam were built on this axis. This pocket would not be under the dam, but it would be in the stilling basin at a point subject to severe erosion. Should similar holes be found under the dam itself, additional expense would be incurred for cleaning out and backfilling them with concrete. The more numerous drill holes in the vicinity of axis No. 3–C do not reveal any similar pocket.

75. The pervious layers of sand and gravel on the right bank which constitute a major problem at all sites are apparently thinner at axis No. 3–C because the overlying till bed extends to a lower elevation. Also, the bank has a gentler slope and is practically free of boulders. There is no surface showing of basalt, and none was encountered in trenches or tunnels. These conditions are important to the control of seepage at the right abutment. The long, concrete cut-off wall proposed for the purpose will be less expensive because of the absence of basalt, the greater uniformity of materials to be penetrated, and the gentler slopes providing readier access to the workings. This axis is nearest to Bridgeport and Brewster, requiring less railway and highway construction and providing superior space at the site for construction activities, storage yards, shops, and railway sidings. Suitable temporary and permanent housing sites are correspondingly closer to the job.

76. Axis No. 3–C provides better opportunity for future expansion in generating installation at less cost than does any other location considered. The foundation rock is shown by numerous drill holes to be of quite uniformly good quality throughout the area. The available head is slightly greater, and the tailwater level is susceptible of greater improvement. Several local variations of this site were studied and abandoned as disadvantages became apparent or better lay-outs were suggested. Each of the elements mentioned above adds an increment in favor of this site, and the summation definitely points to axis No. 3–C as the best location.

77. *Site geology and foundation conditions.*—Surface relief in the vicinity of the project is rugged. Omak Plateau to the north and Columbia Plateau to the south rise 2,000 feet within 3 miles. From Grand Coulee Dam to the mouth of Okanogan River, a distance of about 63 miles, the Columbia covers the full width of the canyon bottom with no flood plains in the entire reach. The canyon was excavated largely in glacial sediments that partially fill a broader, preglacial valley. About 75 percent of the exposed reservoir wall is glacial debris and about 25 percent is bedrock. At Foster Creek Dam site the left river bank consists of the preglacial valley wall, whereas the right bank is glacial sand, gravel, and till.

78. Geologic sections of the dam site, as developed from the subsurface explorations, are shown on plate 10.[1] The topography on the right bank at the dam site is characterized by broad, flat terraces and intervening scarps, varying in height from 10 to 80 feet. Within the area that will be of interest during construction, the greatest relief is about 260 feet. The right bank rises with a slope of 1 on 2 directly from elevation approximately 770 at the water's edge to a terrace at approximately 1,030 feet. The left bank rises about 200 feet within the construction area. The lower part is an almost vertical cliff about 80 feet high. Above that, the slopes are broken and, in places, reversed.

79. Foster Creek Rapids are formed by granite bedrock related to the granites lying north and east. Bedrock underlies the river bed at depths varying from a fraction of a foot to 10 feet and continues under the right bank glacial materials, rising gradually to outcrop at elevation 1,100 feet some 4,000 feet north of the river. Bedrock also forms the entire left abutment and, at varying depths beneath the glacial

[1] Not printed.

overburden, furnishes the foundation for powerhouse and appurtenant works. It is granodiorite (elsewhere called granite) and is generally fresh and hard, medium- to coarse-grained, and gray to pink in color. It is stable chemically, not subject to disintegration in water or alkaline solutions. Logs of the drill holes are shown on plates 8 and 9.[1] They reveal sound rock at depths of 20 feet or less below rock surface over most of the foundation. Considering the area as a whole, the foundation rock is of good quality and the stripping required will be light to moderate.

80. *General lay-out.*—The proposed lay-out is shown on plate 11.[1] The dam will be of concrete, straight, gravity, overflow type with stilling basin at approximate stream bed elevation. The greatest practicable length of spillway is required to pass the design flood of 1,250,000 cubic feet per second with reservoir water surface 50 feet above the crest; hence the spillway will occupy the entire width of the river channel and will cut into the bank slopes on both sides. Its south end will rest on a series of steps cut into the granite abutment and will be joined by a short nonoverflow section founded on top of the granite shoulder. A nonoverflow section north of the spillway will extend into the right bank and be joined to the cut-off through the pervious gravels that form the lower portion of the bank.

81. Foundation conditions dictate that the intake, penstocks, and powerhouse be located on the left bank, extending downstream. The intake wall will be on relatively high rock, roughly paralleling the bank. The approach channel and intake canal will involve a large volume of rock excavation. Drill holes, rock outcrops, rock cuts in the highway, and the contour of the ground suggest a sharp drop in the rock surface just north of the intake wall. This permits the powerhouse to be close to, and parallel with, the intake wall and to have correspondingly short penstocks. On the other hand, the tailrace will require heavy excavation, but a large portion of it will be loose material, some of which can be used to fill the electrical switchyard area south of the intake canal, and to grade a lookout point for visitors around the granite knob south of the intake canal entrance. The elevation at top of spillway gates will be 940 and normal pool elevation, 937.5. Backwater studies indicate that the head gained at Foster Creek, minus some loss of head at Grand Coulee, reflects an over-all advantage in raising Foster Creek pool to this elevation. Backwater studies are covered in appendix IV.[1] The estimated water elevations at 1,250,000 cubic feet per second spillway design flood and the principal structural elevations at top of dam controlled thereby, are shown in pertinent data, table 1, at the beginning of this report.

82. Permanent housing, together with the necessary community facilities, will be located on the high bench between Foster Creek and Bridgeport. Access to the job from Brewster will be furnished by a construction railway and a highway located along the right bank of the Columbia. To accommodate the heavy loads of machinery and equipment and the large volume of traffic, new combination railway and highway bridges will be required over Okanogan and Columbia Rivers and Foster Creek.

83. *Dam.*—The spillway will be 1,192 feet long and have an estimated height of 220 feet from foundation to roadway, as shown on

[1] Not printed.

plate 12.[1] It will have the conventional ogee form with stilling basin at the base of the dam and parallel training walls along the sides. The energy of the falling water will be dissipated by a hydraulic jump in the stilling basin. Final design of this feature will be determined by model tests. The retaining wall along the right bank of the stilling basin will be a high, gravity section founded on rock, whereas the wall along the left bank will consist largely of concrete lining anchored to the rock face. A concrete apron will be provided as a floor within the stilling basin. The extent of the apron may be reduced if the rock is found to be sufficiently resistant to erosion and if consistent with model tests. The sill at the downstream end of the stilling basin will have supports for a temporary bulkhead to permit unwatering the basin if necessary. A more detailed discussion of spillway hydraulics is contained in appendix IV.[1]

84. Crest discharge will be controlled by 25 tainter gates, each 40 feet long by 32 feet high (above spillway crest), supported by 8-foot piers. Each gate will be operated by an independent, motor-driven hoist. Vertical stop-log slots will be located in the piers upstream from each gate. For emergency use and repairs, stop-logs sufficient for closing two gate openings at a time will be provided. The spillway will be surmounted by a reinforced concrete operating bridge with roadway, resting on the piers. The bridge will support the individual gate hoists and will carry a 50-ton traveling crane for handling the stop-logs. Tracks for the crane also will pass over the tainter gate hoists to permit emergency operation of the gates if the regular mechanism should fail. Access to the roadway by truck will be provided. Twelve rectangular sluice conduits, each 5 feet 8 inches by 10 feet 0 inches, will be located slightly above normal tailwater to aid in handling the river during construction and for possible emergency partial draw-down of the pool thereafter. Each conduit will be controlled by two slide gates accessible from galleries within the dam. The load assumptions and stability analyses are treated in appendix III.[1]

85. Provision is made in the estimates for clearing all trees and other buoyant debris from the reservoir area. Columbia River Reservoir was cleared thoroughly before it was flooded and little bulky flotsam has been encountered at Grand Coulee Dam. However, no large flood has occurred since it was filled. Inasmuch as Foster Creek crest gates will be only about one-third as wide as those of Grand Coulee, floating objects which would pass the latter might occasion difficulty. Therefore, a heavy diagonal boom is contemplated above the dam which will divert debris to the right bank where it may be removed by winch. Anything that might escape the boom and lodge at the gates may be removed by the gate and stop-log crane.

86. The dam, intake wall, retaining walls, and apron will be divided into blocks by contraction joints. Joints of the spillway section will be spaced 48 feet center to center through the height of the dam and in line with centers of gateways. Thus each block will carry a pier at its center. It is proposed to make the joint spacing in the intake structure containing penstocks correspond to the spacing of the generating units. Joint spacing in the remainder of the structure will be approximately the same as in the spillway.

[1] Not printed.

87. *Right abutment, cut-off, and retaining wall.*—The control of seepage through the right abutment is the most serious engineering problem connected with the project. A layer of pervious gravel overlies the bedrock to a depth of about 110 feet at the river bank, becoming gradually thinner with distance from the river. Its lower one-quarter to one-half is below ordinary river levels and, therefore, is saturated at all times. It contains large glacial boulders. Over the gravel lies a mass of impervious till about 150 feet thick, extending almost to the surface. The upper 20 to 40 feet of material is fine sand which forms a fairly flat ground surface at elevations from 1,030 to 1,050.

88. Positive prevention of seepage through the gravel bed of the right abutment is proposed by construction of a concrete cut-off wall along a northerly extension of the dam axis from the end of the nonoverflow section some 2,600 feet to the point where bedrock rises to normal pool level. Vertically, the cut-off wall will extend from bedrock to the under side of the impervious till layer with which it will be joined to form a continuous seal. The difficulty of access to the cut-off operation through or beneath the deep till mass will constitute an important item of cost.

89. The relative positions of the pervious and impervious layers create an additional problem because of the probability of bank slides when the reservoir is filled; particularly in case of rapid draw-down. Such slides have occurred in the Columbia River Reservoir where similar bank materials exist. The natural bank slope is 1 on 2, but this will be modified to 1 on 3 in the immediate vicinity of the dam to prevent sliding. The final slope determines the length of nonoverflow section required. This section and its joint with the cut-off wall can be built in open excavation and backfilled with rolled, impervious material placed in the dry with a surface slope toward the river of 1 on 1. This fill will be considerably thicker than would be required if it served only as a blanket. It will be protected by a thick rockfill, paved with concrete on a slope of 1 on 2 at the toe, to resist erosion by the high-velocity current passing over the adjacent low block during construction. Above the concrete paving the slope of the rockfill will be 1 on 1¾. The backfill will furnish lateral support for the thin concrete cut-off wall and will serve to exclude the river, permitting excavation for the cut-off wall through the gravel to continue after the cofferdam is flooded.

90. The waterway width required for spillway and stilling basin extends these sections well into the lower slope of the right bank, causing a cut 85 feet high. A gravity wall, built as a continuation of the right spillway training wall, will retain the bank. At its downstream end beyond the stilling basin sill, the front face of the retaining wall will be warped gradually to a slope of 1 on 1, forming a transition between the vertical slope and the riprapped bank farther downstream. Drainage will be provided by a layer of coarse gravel against the back of the wall.

91. *Left abutment and intake works.*—The left abutment, which rises sharply for about 100 feet under the south end of the spillway section, is granite of good quality. The short, nonoverflow section at this end will connect with a high, gravity, intake wall extending downstream nearly perpendicular to the axis of the dam, as shown on